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Mobility with QoS in Broadcast Unidirectional Technologies: Experimental Validation

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Abstract – Although mass entertainment markets, such as entertainment TV, were previously on the control of broadcast operators, the increased interest in supporting these multimedia services "anywhere and anyhow" is driving the interest of wireless operators. Therefore, the integration of broadcast technologies in the next generation networks is now a reality. However, since broadcast technologies are unidirectional, their use in mobile interactive communications requires the support of other technologies to enable the upstream communication through a return channel.

This paper presents an experimental setup of the architecture developed in the framework of the IST-Daidalos project that is able to provide multimedia and interactive services through a heterogeneous network integrating DVB technology, and enabling seamless and media independent handovers with QoS support. The experimental testbed contains DVB, UMTS, Wi-Fi and Wi-Fi with WiMAX as backhaul technology, and supports seamless handovers with QoS between these technologies, integrating also handover of different return channels. The results show that the handover impact is more noticeable in handovers to DVB and UMTS technologies, when compared to Wi-Fi and WiMAX ones. Nevertheless, when the network is not overloaded, the handover timings do not exceed 200 msec.

Index Terms — **QoS, mobility, broadcast, return channel, media independent handovers, experimental testbed.**

I. INTRODUCTION

The increased demand for multimedia services by mobile end users in recent years has driven both broadcast and wireless network operators to develop new systems and architectures for the deployment of such services. The advent of new broadcast technologies enables the support of novel business models, thus creating attractive environments both for fixed and mobile operators. The broadcast technologies support large bandwidths and can be used for the transport of data based services. However, they are inherently unidirectional, lacking the support of interactive applications; therefore, it is required to resort to other technologies for the uplink channel. Either making use of IEEE 802.11 (WiFi), UMTS, IEEE 802.16 (WiMAX) or any other type of link, there must be a platform to integrate such specific technologies, in order to assure service provisioning with mobility support and QoS assurance, through coordination between both downstream and upstream technologies.

To increase the attractiveness of broadcast services to service providers, a network has to provide a unified platform that serves unicast as well as multicast services in a unified way. Moreover, the high spectrum efficiency and the ability to serve many (thousands to hundreds of thousands) fixed and mobile receivers by one powerful fixed sender makes unidirectional broadcast technologies, such as DVB-T/H, a perfect choice for many multicast-based services, such as distribution of media contents, carousel applications, one-to-many file downloads and video streaming. On the other hand, a typical scenario for DVB-H, can be the delivery of video streams, gaining additional revenue from the transfer of news, sports, weather and other contents on demand using interactive channels. Therefore, the support of interactive channels simultaneously with QoS and mobility, in a unidirectional broadcast technology is not a trivial task. From one side, L2 tunneling mechanisms over uplink paths need to be present to hide this asymmetry and treat unidirectional technologies like bidirectional ones. From the other side, QoS needs to be assured for both technologies and seamless mobility of both unidirectional and return channels needs to be in place. Moreover, coordination between QoS and mobility mechanisms when different technologies are used for both downlink and uplink channels is extremely important, to be able to provide seamless mobility to the services and users. Most important, we aim at providing a unified, homogeneous architecture whose control interfaces and features shall not differ if a service is delivered using a broadcast technology. Therefore, seamless QoS and mobility support shall be achieved by a common architecture based on mechanisms common to all networks.

These challenges have been a particular focus of EU IST project Daidalos [1]. This paper proposes a solution for integration of broadcast technologies in 4G networks with QoS and mobility. This solution is characterized by a hierarchical structure to support QoS, and extends the current Media Independent Handover standard IEEE 802.21 [2] to seamlessly integrate mobility and QoS in unidirectional technologies environment, integrating the support of return channels. This architecture was implemented in a real testbed with mobility of users between different technologies, from Wi-Fi (in both direct and return channel) to DVB with UMTS as a return channel, and from DVB with UMTS as return channel, to Wi-Fi (using WiMAX as backhaul network). The results show that the architecture supports the seamless mobility of users when broadcast unidirectional technologies are in place, with low performance degradation on the running communications. To our best knowledge, this is the first real demonstrator containing QoS and mobility with broadcast unidirectional networks integrating the return channels, and including all these technologies.

This paper is organized as follows. Section II presents the related work and the support of unidirectional and return channels. Section III depicts the network architecture, while section IV and VI present solutions for QoS and seamless mobility support in broadcast networks. Section VI presents the real testbed and the obtained results for mobility. Finally, section VII concludes the paper and introduces areas for further work.

II. RELATED WORK

In the literature, there is significant work on unidirectional links, mobility and QoS, but less work on the integration of broadcast in heterogeneous networks.

Concerning mobility, there is already much work on mobility protocols, such as Mobile IP based approaches [12], several fast

mobility approaches (FMIP [4] and HMIP [5]) and new concepts for local mobility (PMIP [3]). Recently, the IEEE 802.21 and its Media Independent Handover Function (MIHF) [2] between the link layer and higher layers and its messages can enable handover across heterogeneous wireless networks. However, the interaction with DVB is not straightforward. Concerning QoS, although there is much work on QoS architectures [7][8][9][10], and its integration with mobility [11], none of them addresses the support of DVB unidirectional networks.

Concerning unidirectional links, the Link Layer Tunneling Mechanism (LLTM) defined by the UDLR WG [21] is the most common approach of integration while not considering mobility itself. This mechanism provides an emulated, virtually bidirectional interface and is based on the permanent availability of a bidirectional Internet connection, e.g. one bidirectional link. LLTM assumes the tunnel endpoints to be broadcasted using the Dynamic Tunnel Configuration Protocol (DTCP) which would imply a major delay in tunnel setup when a unidirectional handover takes place. Therefore, in our work we propose to acquire this information in advance using IEEE 802.21 Information Service. When using this approach, only few elements and protocols need to specially consider unidirectional links: first, the mobile node has to be aware that this interface needs another interface as a return channel e.g. when handover to that interface takes place; second, and more complex, unidirectional links in particular need special consideration in the QoS management. The mechanisms developed in our work are described in sections IV and V.

In [16], the integration of DVB-T with Wi-Fi/UMTS as a return channel is presented. This work assumes handovers only for a return channel due to very wide coverage of DVB-T technology. The Daidalos approach goes much beyond: it assumes that both upstream and downstream channels can be handover at any time, and handovers can be provided between bidirectional and unidirectional technologies. In the Daidalos approach, integration of QoS and mobility for unidirectional broadcast network has been implemented. A very early stage work on the support of return channels was presented in [18]. The overall high-level Daidalos network architecture can be found in [19], and very early stage experimental results with a simplified mobility approach, only between DVB and Wi-Fi, and no QoS support are presented in [20]. In this paper, we present seamless handover with QoS in heterogeneous networks integrating DVB, where all possible handovers are supported and experimentally tested: mobility between DVB with UMTS as return channel, Wi-Fi and WiMAX.

III. QoS and Mobility Architecture for Broadcast

The network architecture is presented in Figure 1. A hierarchical network of three levels provides scalability of QoS resource management and efficient terminal mobility control in wireless environment. The top level is a core network, where per aggregate traffic management using DiffServ [13] model of resource management is provided. At lower layers per-flow resource management is implemented to enable efficient resource management of wireless networks. At core network, the mapping of flows to aggregates is performed. The second level is formed by Local Mobility Domains (LMDs) that are responsible for terminal mobility management and integration of several heterogeneous access networks which form the lowest level of the architecture.

The mobility management is divided on Global Mobility Management where MIPv6 is used and Local Mobility Management (LMM) implemented in LMD. The LMP (Local Mobility Protocol) designed in Daidalos implements LMM by

integration of concepts proposed by IETF NetLMM [14], a hierarchical Mobile IP [4] and an IEEE 802.21 Media Independent Handovers (MIH) standard [2]. The IEEE 802.21 is used as the common denominator that abstracts the heterogeneity of the access technologies, and will also be extended to include QoS provisioning and mobility. This architecture is compliant with 3GPP that already makes use of IEEE 802.21 for heterogeneous mobility. Resource management can also be seamlessly integrated. Moreover, this integrated approach with IEEE 802.21 can also be applied to Session Initiation Protocol (SIP) mobility to help on the handover preparation process. In this case, specific triggers and actions need to be specified to integrated SIP and IEEE 802.21 signalling.

In the architecture, access routers (ARs) connect mobile terminals (MTs) to LMDs. To support QoS and mobility, several modules have to be deployed in MTs and ARs. The common modules are: RAL (Radio Access Layer) to unify the access to different access technology mechanisms, and MIHF (MIH Functions) which implements IEEE 802.21 functions. In MT the MTC (Mobile Terminal Controller) implements an interface selection algorithm and controls UDLR [21] (Unidirectional Link Routing) tunnels, used to hide heterogeneity of upstream and downstream channels from applications (when DVB is used). Also in the MT, a QoS Controller (QoSC) is responsible for interactions with applications, L3 end-to-end QoS signaling, and interoperation between QoS and mobility modules in MTs. As L3 end-to-end QoS signaling, Next Steps In Signaling (NSIS) [15] protocol suit has been chosen. In ARs, there are L2QoSC modules responsible for QoS management in access networks (AN), and QoSM (QoS Manager) responsible for L3 QoS signaling and the control of terminal access to the network using QoS mechanisms.
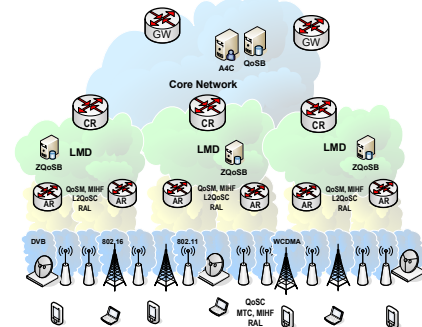
Figure 1: Network architecture

The main entity managing QoS in LMD is the ZQoSBr (Zone QoS Broker), which controls all routers in the domain. ZQoSBr is also a policy enforcement point of A4C (Authentication, Authorization, Accounting, Auditing and Charging) subsystem, controlling access to the network by QoS mechanisms deployed in ARs. A top level QoSB (QoS Broker) module is responsible for QoS resource management: in the core network, and between the Daidalos domain and external networks.

IV. QoS and Broadcast

The support of QoS involves new functionalities on the mobile terminals (MTs), specific signaling to the network, application-specific QoS parameters and resource reservations over the end-to-end path. This section presents the process of QoS session setup in broadcast networks for a unicast scenario. Between terminal and network (and end-to-end support), the NSIS protocol is used to provide QoS signaling. In the core network, the NSIS signaling is mapped to the Diffserv aggregates, so it is very important to ensure

appropriate resource reservation along the whole data path. The resource management in core networks is out of scope of the paper.

The enhancement of applications with QoS is a challenge for broadcast environment, since downstream and upstream flows can be routed through different paths, which involves additional signaling for an end-to-end coverage. The MT should never perform resource reservations directly on the access links, so the reservations must be requested to the network, since QoS requests must be established over the end-to-end path between the MTs.

Figure 2 illustrates the process of QoS reservations for uplink channel for a QoS session initiated by MT. The MT starts the sessions with the QoS requirements indicated by the QoS Specification (QSPEC) objects within the *NSIS_Reserve* messages, sent by the QoSC to ARs. Through an interface selection algorithm, it is selected an outgoing interface taking into account the flow parameters. For upstream flows, two NSIS reservations are required: the first for the UDLR tunnel between MT and DVB-AR, and the second for the end-to-end connection. For the first reservation, an *NSIS_Reserve* message is sent to QoSM at WLAN AR. At DVB AR, which is listening for incoming packets on its tunnel endpoint, QoSM receives from QoSC the request message for the end-to-end reservation. Both ARs query their local ZQoSBs respectively, to perform user admission control, through Diameter [23], and A4C servers are contacted to validate the user access rights. If the user is not registered, all resource requests are denied and an appropriate error is returned to the application. On the other side, if the user is registered and the request is authorized based on the availability of resources, L3 QoS resources on the direct links between both ARs and the MT are now pre-allocated (L2 reservations, not shown in the diagrams, are also performed).

Next, for the UDLR tunnel reservation, the QoSM at the WLAN AR sends an *NSIS_Reserve* message to the QoSM at the DVB AR. If authorization is granted, the QoSM pre-allocates resources for the return tunnel between the two ARs. Then, the DVB AR contacts the ZQoSB again to effectively install the previously pre-allocated resources, and a positive answer will indicate that resources were installed at the DVB AR. Then, WLAN AR communicates to ZQoSB and allocates recourses for the UDLR tunnel using L2QoSC module, and the reservation for the UDLR tunnel is set up.

The end-to-end QoS negotiations must continue to the next hop until they reach the correspondent node (CN). Therefore, the DVB AR sends an *NSIS_Request*, but this message will not be processed at the intermediate nodes in the core; instead, reservations are performed through DiffServ, where local QoSBs perform admission control and install filters at their controlled routers.

When the CN domain accepts the connection and the QoS reservations are performed by interacting with the local QoS entities, CN replies with an *NSIS_Response* message that is sent downwards, and the same process happens in all nodes all the way down to the DVB AR. When that response arrives at the DVB AR, the QoS reservations will be installed at L3 and L2 in the correct interface that is directly connected to the MT; when the *NSIS_Response* reaches MT, the end-to-end reservation is set up.

Figure 2: QoS session setup for an upstream path

To perform L2 reservations (not shown in the figure due to simplification purposes), the MIH framework is extended with QoS support, where MIHF acts as an intermediate layer to translate the L2 reservations to the particular access technology RAL, which in turn exchanges signals with the corresponding driver. In this sense, the L2QoSC issues a *MIH_Resource_Prepare.request* towards the MIHF, and the MIHF forwards the resulting output (*Link_Resource_Prepare.request*) to the RAL; if the RAL accepts the request, the answers are sent upwards.

The QoS session setup for downstream flows consists by one end-to-end reservation between CN and MT. The rules for setting up the reservation are the same as for the upstream end-to-end reservation. The only differences between upstream and downstream reservations are: the direction of the reservation, and the existence of one more NSIS message in the downstream reservation, which is used to initiate the reservation by the receiver of a data flow.

V. MOBILITY SUPPORT

In the mobility process, we provide a fast, seamless and QoS-supporting handover mechanism. In our approach, the mobility management makes use of Network-based LMM, which allows the network to maintain a certain address for a mobile node throughout the management domain. Moreover, the required mobility signaling remains domain-local.

In order to facilitate a unified local control of network interfaces and a unified management of network attachment, the IEEE 802.21 is used. This standard defines interfaces and messages which allow a local network manager to configure the local interfaces, e.g. to attach to a given network, and to cooperate with ARs in order to manage MT related state. We extended the set of managed state by QoS and multicast properties, which allows to transfer state from one AR to another in a unified way and taking into account unicast as well as multicast services while preserving QoS reservations. All this process is performed in combination with the LMM, which allows to minimize the interruption and packet loss caused by the handoff. The detailed process for a handover from Wi-Fi (WLAN) to DVB using UMTS for LLTM return channel tunneling will be described in the following. The MIH based handover consists of three phases as depicted in Figure 3 (simplified):

▪ Initiate phase: the MT finds out if a handover to a specified network is possible, taking A4C and QoS into account.

▪ Commit phase: MT decides to execute the handover, the resources in the new access network are allocated, and the MT triggers the L2 handover.

▪ Complete phase: MT is attached to the new network and the resources in the old access network are released.

All three phases use a MIH signaling between MIH functions in different entities in the network. The process starts when the MT decides to move to another point of attachment, most probably based on MIH events e.g. informing about a low Signal to Noise Ratio (SNR) for the old access network. The MT then sends a *Handover Initiate Request*; this message contains the information of the network the MT intends to move. This information is forwarded to the ZQoSB which checks for resource availability and prepares the resources in the new network. If the ZQosB of the two networks differ but are in the same domain or in sufficiently federated domains, *Diameter* signaling is used between the brokers (not covered in the figure). When a positive answer reaches the MTC, it will switch to commit phase and send a *MIH Handover Commit* message. When it reaches the ZQoSB, it reserves L3 resources to the new access network and triggers L2 reservations in the specific technology through the RAL in the ARs. If the MT listens to a multicast session, it will also trigger the Multicast Controller (MCC) of the AR of the new access network to join the respective multicast streams (Source, Group) in advance. When the *Commit Response* message reaches the current mobility gateway, it will start bicasting unicast packets to its own and the new access network which is the DVB access network. When this process is completed, the MT is informed by a MIH response message. At this stage, all resources in the network are ready for the MT to handoff. This consists, in the case of broadcast technologies, of two phases: the attachment to the unidirectional network and the establishment of the LLTM tunnel to the DVB-MAG. This tunnel in this case is routed via a third network, e.g. a UMTS link. This third technology does not appear in Figure 3 because the usage of this link is completely transparent to the mobility management. After the attachment to the new network, the new location will be registered in the LMA and the MT will receive a coordinated *Router Advertisement* advertising the same prefix. Therefore, the address will not change and no global mobility mechanisms are triggered. After that, the traffic of all services handed over, unicast and multicast as well, flows over the new access network which is the unidirectional one. The MT immediately informs the new AR about the successful handover by a *MIH Handover Complete* message. This message is forwarded to the ZQoSB which triggers the release of resources in the old AR. This applies to network resources managed by the QoSM as well as for the Multicast Group Membership. Since multicast group membership is managed explicitly, it is known if there are still listeners for these groups. Then, the MT is informed about the successful completion of the handover.

Please note that there is no need for special handling of the broadcast technology on the mobility level: apart from the attachment to the network which includes QoS supporting tunnel setup, there is no mention of the UMTS return channel link. Using this architecture, all kinds of services, TCP connections as well as multicast streams, can easily be handed over from WLAN to DVB-H (with UMTS for the return channel) and vice versa. This architectural design provides therefore a unified, fast and QoS-integrating mobility support for any kind of service using different networks.
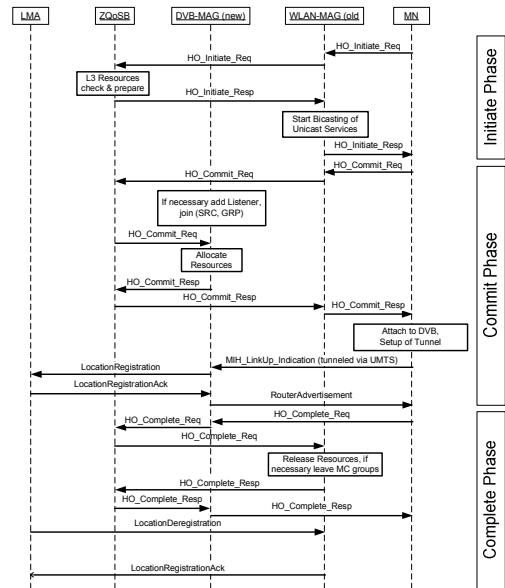

Figure 3: Handover from WLAN to DVB using LLTM with QoS

VI. TESTBED AND EXPERIMENTAL RESULTS

This section contains the description of the testbed used in the real experiments and the most important handover results. The testbed scenario is depicted in Figure 4. It fulfils the hierarchical concept proposed in the overall architecture. The lowest layer includes the MT, which is a Laptop PC that is connected to one of the ARs (depending on the instant time of the experiment), and is communicating with a correspondent node (fixed). The communications include UDP flows and both real-time IPTV (audio and video) streams. Both terminals run a Daidalos II modified kernel with all the changes required for the QoS and mobility support, including the Mobile IPv6 [12] support. The second layer is composed by the access networks, the ARs, connected to different technologies, DBV, UMTS, Wi-Fi and Wi-Fi with WiMAX as backhaul, and by the ZQoSB. The top layer is the core network that contains a Home Agent. The A4C is also used to perform authentication and authorization. The core router connects to the core network; it also works as local mobility anchor, which will be used, together with the Home Agent, to control local mobility.

The core and access networks are built in Ethernet connections with a maximum bitrate of 100 Mbps. The testbed used a DVB-H bursting scheme which provided 4.5 MBit/sec for the logical DVB-H network used. The WiMAX frequency band is 3.5 GHz with a channel bandwidth of 7 MHz, with a maximum bandwidth of 10 Mb/sec per direction. The Wi-Fi (IEEE 802.11b) is configured to the maximum rate of 11 Mb/sec. The UMTS used is an emulated-UMTS through the support of W-CDMA-alike frames, with a maximum transmission rate of 2 Mb/sec.

In the performed experiments, two types of handovers were studied: (1) from Wi-Fi to DVB for the downstream traffic and UMTS as the return channel (handover both for the downstream and uplink channel for two different technologies); (2) from DVB and UMTS (as a result of the previous handover) to Wi-Fi with WiMAX as the backhaul. When a handover is performed, the data is analyzed during this time. The following results contain the mean of 10 different experiments and we present *boxplots* that represent the mean values and their deviation. For accuracy purposes, the nodes are synchronized through the Precision Time Protocol daemon (PTPd) [24], which can synchronize machines in

some seconds with nanosecond precision. The values presented in the following box plots correspond to average values calculated by means of *jtg_calc* [25], which was also use to generate the traffic.
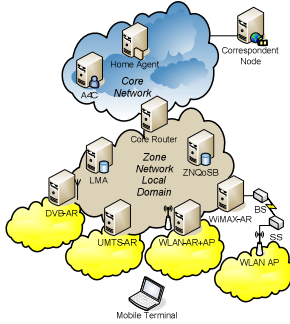

Figure 4: Testbed Scenario

A. Handover performance varying the number of UDP streams

This section depicts the performance of the two types of handovers previously described when varying the number of UDP streams. The UDP streams have a bitrate of 384 kbps.

The first metric presented is the packet loss measured at the mobile terminal for the handover from WLAN to DVB with UMTS, with the increment in the number of streams (Figure 5). In this handover, the packet losses reach values around 5%, only for 1 and 2 UDP streams, with a slight increase with the number of UDP streams. When the handover from DVB with UMTS to Wi-Fi (with backhaul WiMAX) is performed, the losses are lower for larger values of number of streams. This shows the higher ability of WLAN and WiMAX to deal with traffic aggregation when compared to both DVB and UMTS.

The delay values, presented in Figure 6, show an exponential increase with the number of UDP flows, in the case of handover from DVB with UMTS to Wi-Fi (with backhaul WiMAX), which is expected since the load increases. These times are smaller than 10 msec. This shows the low disruption time during handover, since the delay values are similar to the ones of wireless transmission. The handover delay of just one UDP stream is exceptionally high because the off-the-shelf DVB encapsulator used in the experiment was known to only start transmission once the buffer is filled to a certain degree; then, this delay emerges at the DVB encapsulator. From Wi-Fi to DVB with UMTS, channels need to be assigned, which increases the handover times, and consequently, increases the delays to values in the order of 100-200 msec. The unexpected result for the smaller delay with two UDP streams is due to interference with other networks. The jitter, not shown here due to space limitations, does not significantly vary with the number of streams, and it is around 20 msec for both handovers.
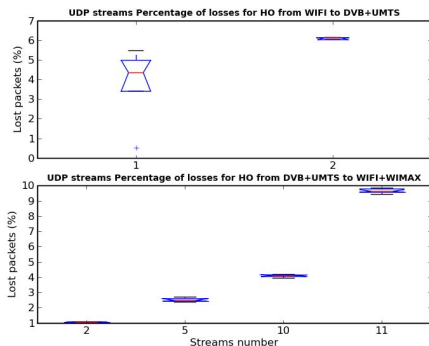

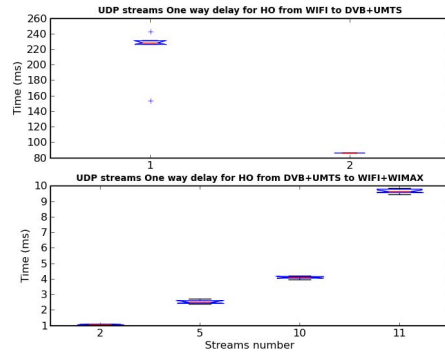Figure 5: Packet losses with varying UDP streams

Figure 6: One way delay with varying UDP streams

B. Handover performance varying the number of IPTV A/V streams

This section depicts the performance of the two types of handovers previously described, but when running several IPTV audio and video flows. The IPTV traffic is based on real audio and video traffic: we used the Jugi's Traffic Generator [25], a Linux traffic generator that allows to emulate IPTV A/V streams based on existing packet traces. The packet traces replicate a real IPTV stream. The video stream was captured in H.264/AVC format and the accompanying audio stream was encoded in MPEG-1 Audio Layer 2. The video was streamed at 512 kbps (Variable Bit Rate - VBR), and the audio at 192 kbps (Constant Bit Rate - CBR). To better show the handover effect in each type of stream, each value on the x axis will have a pair of whisker-boxes, corresponding on the left side to Audio streams and on the right side to Video streams. This applies to all graphics in this section.
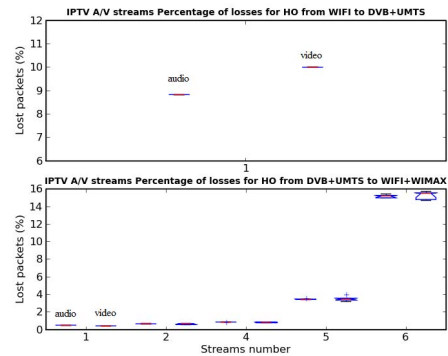

Figure 7: Packet losses with varying IPTV streams

The packet losses, shown in Figure 7, are of 10%, both for Audio and Video in the Wi-Fi to DVB with UMTS handover. This happens due to the higher bit rate of video and its variable bit rate nature, since 512 kbps is the mean rate. In the handover from DVB with UMTS to Wi-Fi, the losses are usually smaller, but it is noticed a high increase at 5 and 6 IPTV streams, which denotes that saturation is reached. The losses are slightly higher in video streams, again due to its variable and higher rate nature. From the loss results, we can conclude that for high loads, the handover has a significant impact in the network performance.

The delay values, shown in Figure 8, have a similar behaviour to the loss ones. With higher loads, when performing the handover from Wi-Fi to DVB with UMTS, channels are reserved and the delay does not significantly increase, and consequently the handover time is not affected. However, when considering handover to Wi-Fi (with WiMAX as backhaul), with 5 and 6 number of IPTV streams the Wi-Fi network is overloaded and the

delay significantly increases. Jitter, not shown, was not affected in this scenario, as its values remain around 20 msec for both handovers.
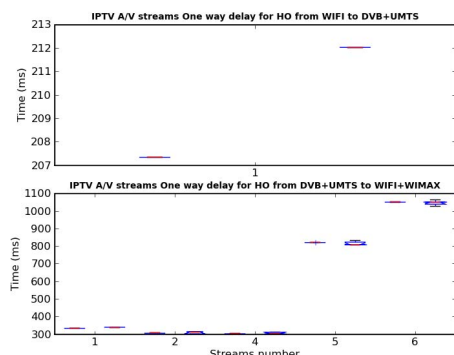

Figure 8: One way delay with varying IPTV streams

Although it is not the objective of this paper to analyze deeply the influence of handover delay and packet loss on application performance (qualitative and quantitative influence of QoS network parameters on application can be found in [26]), the general conclusion is that the achieved results are promising. Even if the perceived service quality of applications may be influenced, the handover can be performed without interrupting the application sessions.

VII. CONCLUSIONS AND FUTURE WORK

This paper presented an experimental evaluation of a heterogeneous network integrating DVB technology, that provides the means to support a return channel for interactive communications, as well as QoS and seamless mobility support for both the direct and return channels. Several handovers were tested, considering technologies such as DVB, UMTS, Wi-Fi and WiMAX. The results show that the architecture supports the seamless mobility of users when broadcast unidirectional technologies are in place, with low performance degradation on the running communications, and with disruption times not longer than 200 msec for non-overloaded networks. This is a great achievement, since we were able to successfully test the seamless support of mobility in all these types of technology, even using different technologies for both downlink and uplink channels.

Future work addresses the support of context-aware networks and how they impact the above architecture.

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